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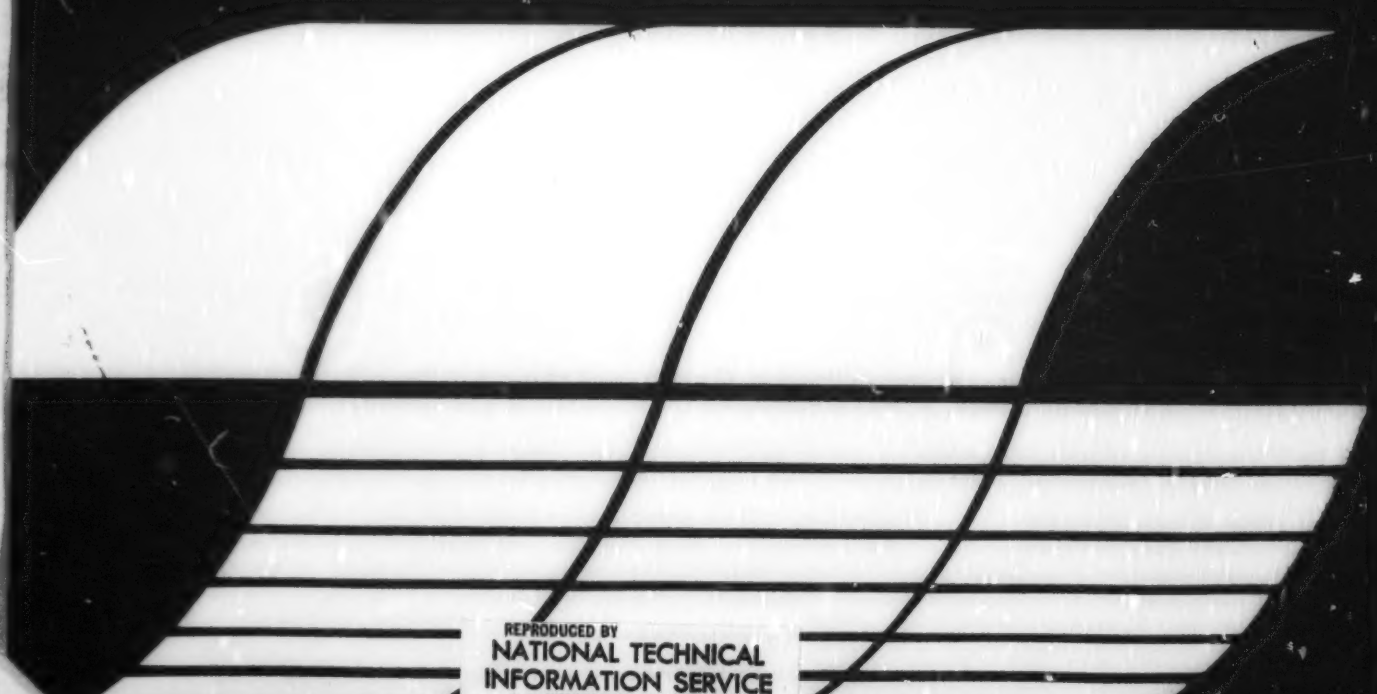
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Research Triangle Park, North Carolina 27711

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EPA RESEARCH IN FABRIC FILTRATION: ANNUAL REPORT ON IERL-RTP INHOUSE PROGRAM

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EPA RESEARCH IN FABRIC FILTRATION: ANNUAL REPORT ON IERL-RTP INHOUSE PROGRAM

by

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16. ABSTRACT The report summarizes EPA's inhouse research program in fabric filtration, involving investigations into the basic mechanisms of dust/fabric interaction in order to develop improved understanding of the process. Evaluation of new fabrics in laboratory tests that can be extrapolated to field applications is a second major goal of the inhouse research. Among the fabrics evaluated were a spunbonded nylon (Cerex), a spunbonded polyester (Reemay), and expanded polytetrafluorethylene (PTFE) laminate (Gore Tex/Nomex), and various specially developed fabrics, including uncalendared needled felts and coated fibrous glasses. These fabrics all performed well or exhibited some desirable property. Other fabrics, less attractive for particulate control, were tested less completely. Development of a mathematical model capable of predicting fabric filtration performance was attempted. The complexities of this task led to breaking the overall process into simpler subdivisions for study, including: particle penetration mechanisms, temperature and age effects, bag cleaning techniques, and electrostatic effects.					
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PREFACE

A key mission of the Environmental Protection Agency is to support the development of technology needed to monitor and control environmental pollutants. This report reviews the EPA in-house research program in fabric filtration that was initiated by the Division of Control Systems/EPA, Cincinnati, Ohio, and continued by the Industrial Environmental Research Laboratory/EPA and its predecessor divisions at Research Triangle Park (RTP), N.C. The report is the first annual report on fabric filtration to originate at RTP; it describes projects undertaken in the preceding 5 years. The work was performed by what is now the Particulate Technology Branch (PATB) under James H. Abbott, Chief. PATB is responsible for advancing technology in the area of fine particulate collection control devices, and is in IERL/RTP's Utilities and Industrial Power Division (UIPD) under Everett L. Plyler, Director.

The present staff involved in the in-house program consists of R. L. Ogan and Dr. J. H. Turner.

British units primarily are used throughout this report in order to preserve the constants, scales and plots in which the original work was performed. The Appendix lists conversion factors for computing the metric equivalents of all British units used in the report.

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SECTION 1

INTRODUCTION

During the last 5 years baghouses have gained at least limited industrial acceptance as particulate control devices for coal-fired emission sources, especially because of their efficiency in removing fine particulates ($0.01\text{ }\mu\text{m}$ to $3.0\text{ }\mu\text{m}$ effective diameter). This growing interest in fabric filtration places new importance on EPA fabric filtration research and on the in-house experimental program in particular. More questions about baghouse performance, costs and suitability for specific applications, particularly coal-fired boilers, are being asked by potential users, more requests for guidance are being received and, as baghouses continue to grow in field use, more demands for answers and information are anticipated. Already part of the in-house program is in direct response to such inquiries; the primary part, of course, is in support of the development of basic understanding of fabric filtration and of the development of an optimum or near optimum technology for carrying it out.

The EPA in-house fabric filtration laboratory is a unique facility made up of equipment chosen to be the smallest elements compatible with adequate simulation of baghouse field operation. A commonplace failing of much fabric filtration research and development is that experimental studies carried out on clean, flat fabric samples often bear little relation to the actual fabric filter operation in a baghouse in the field. The EPA in-house facility represents an attempt to create a facility capable of meaningful simulation.

Fabric filtration as a technique for controlling emissions is already a multi-million dollar industry, ranking behind electrostatic

precipitators (ESPs) in annual dollar volume but well ahead of wet scrubbers. Two factors augur well for accelerated growth of fabric filtration at the expense of ESPs:

- 1) Increasingly tougher particulate emission laws which are just beginning to include a fine particulate emission standard (ESPs generally must be made larger in order to meet fine particulate standards; baghouses generally do not require any modification).
- 2) The added cost and size of ESPs designed to control emissions from low sulfur coal.

Both of these factors have led to a growing interest in fabric filtration as an alternative or, more and more now, a preferred particulate control device for both industrial and utility-owned coal-fired boilers. This trend is in its infancy but, if fabric filters capture even a fraction of the projected market, the impact of this new area of use upon the baghouse industry will be major. Power generation and, to a lesser extent, other combustion sources, such as incinerators, possess the potential of increasing the investment in fabric filter installations by an order of magnitude over the next 10 to 20 years [Ref. 1].

Key factors influencing this trend are costs (both initial and operating), performance (particulate removal efficiency, especially of fine particulates) and high temperature compatibility. Most existing baghouses operate at low temperature (<200°F). For coal-fired boiler emissions (or combustion sources in general) the baghouse will have to operate at higher temperatures. The highest temperature for continuous baghouse operation at present is in the 500-550°F range. Because this temperature range is often restrictive, the development of baghouses and filter fabrics capable of higher temperature operation is one general goal of fabric filter research. The in-house program at EPA has included evaluation of candidate high temperature fabrics and measurement of their endurance under high temperature operation.

Measurement of fabric performance and identification of those fabric/dust properties that influence performance and cost of performance provide the background for the development of optimum fabrics and operating conditions, a second general goal of the in-house research. For baghouses to become the preferred control technology for combustion sources, they must not only be able to control emissions as well as or better than the competitive methods (baghouses are generally now granted this edge), but must do so at a price competitive with the alternative methods. Cost competitiveness is not always conceded to baghouses. Development of fabrics and technology for baghouse operation at lower drags and longer life continues as a specific goal of the EPA in-house research.

The in-house research also has the beneficial side effect of providing EPA with first hand information and experience with which to guide the contract/grant program. Knowing the problems because of personal experience provides invaluable insight for making the decisions required to direct and assess the work of others. Consequently, the in-house program serves to keep EPA abreast of the state-of-the-art as well as being an independent research facility making original contributions to the fabric filtration community.

The facilities used in carrying out the in-house program are described in this report along with a preview of more versatile fabric filtration test apparatus now under construction. The report also reviews specific research activities associated with the various experimental stations and outlines future plans and directions of the in-house program.

SECTION 2

CONCLUSIONS

The EPA in-house research program in fabric filtration consists of two independent, concurrent activities: the evaluation of candidate fabrics and the investigation of basic phenomena. Both activities will continue using existing test facilities and new, more versatile equipment scheduled to be put in service during 1977.

Accomplishments of the fabric evaluation program include:

- 1) The demonstration of superior filtration performance by spunbonded fabrics when compared to similar weights of woven fabrics of the same fiber. The laboratory evaluation justifies field evaluation of this type fabric.
- 2) The confirmation of the unique filtering action of one of the classes of PTFE laminate fabrics. The fabric evaluated filtered flyash very efficiently and showed promise of being especially effective for the filtration of respirable particulates (0.01 μm to 3 μm).
- 3) The identification of polyester as a suitable candidate fabric for filtering cotton dust.
- 4) The measurement of the performance of uncalendared needled felt fabrics in the pulse-jet unit and the measurement of the endurance of variously coated fibrous glass fabrics in the high temperature baghouse.

Specific research topics investigated included:

- 1) Filtration Modeling
- 2) Particulate Penetration
- 3) Fabric Aging Effects
- 4) Particle Size Effects
- 5) High Temperature Effects

Individual reports (in print, in press, or in preparation) describe the details of each of the fabric evaluations and each of the research topics.

SECTION 3

PROGRAM DESCRIPTION

3.1 SHAKE-CLEANED BAGHOUSE

The busiest apparatus used in the in-house research program has been the shake-cleaned baghouse. As many as three single-compartment baghouses, operated as shake-cleaned baghouses, have been on line at one time. These units were essentially identical in design and were used interchangeably in certain studies. Their design and operation are discussed in this section first (3.1.1), followed by a resume of the work performed (3.1.2).

3.1.1 Description of the Shake-Cleaned Apparatus

The typical shake-cleaned baghouse used in the EPA in-house research consists of a single-bag compartment with dimensions as shown in Figure 1. A cylindrically sewn test filter bag is suspended vertically between two mounting nipples: the top attachment is the entry port for the dirty test dust; and the bottom attachment is the exit port to the dust collection hopper. In operation the dust-laden air from the dust feeder enters the inside of the bag at the top. The bag traps and removes the dust from the air which passes through the fabric bag walls. This cleaned air exits the baghouse compartment through a line leading to a blower. The removed dust remains on the inside surface of the bag until the air flow is stopped and the bag is shaken by the mechanical linkage attached to the shaker. The contact between the shaker mechanism and the bag is near the bottom of the bag. The shaking action dislodges the dust from the inside surface of the bag, causing the dust to fall into the collection hopper. After the bag is cleaned, the dirty air flow is turned on again and the filtering is resumed until the next cleaning period.

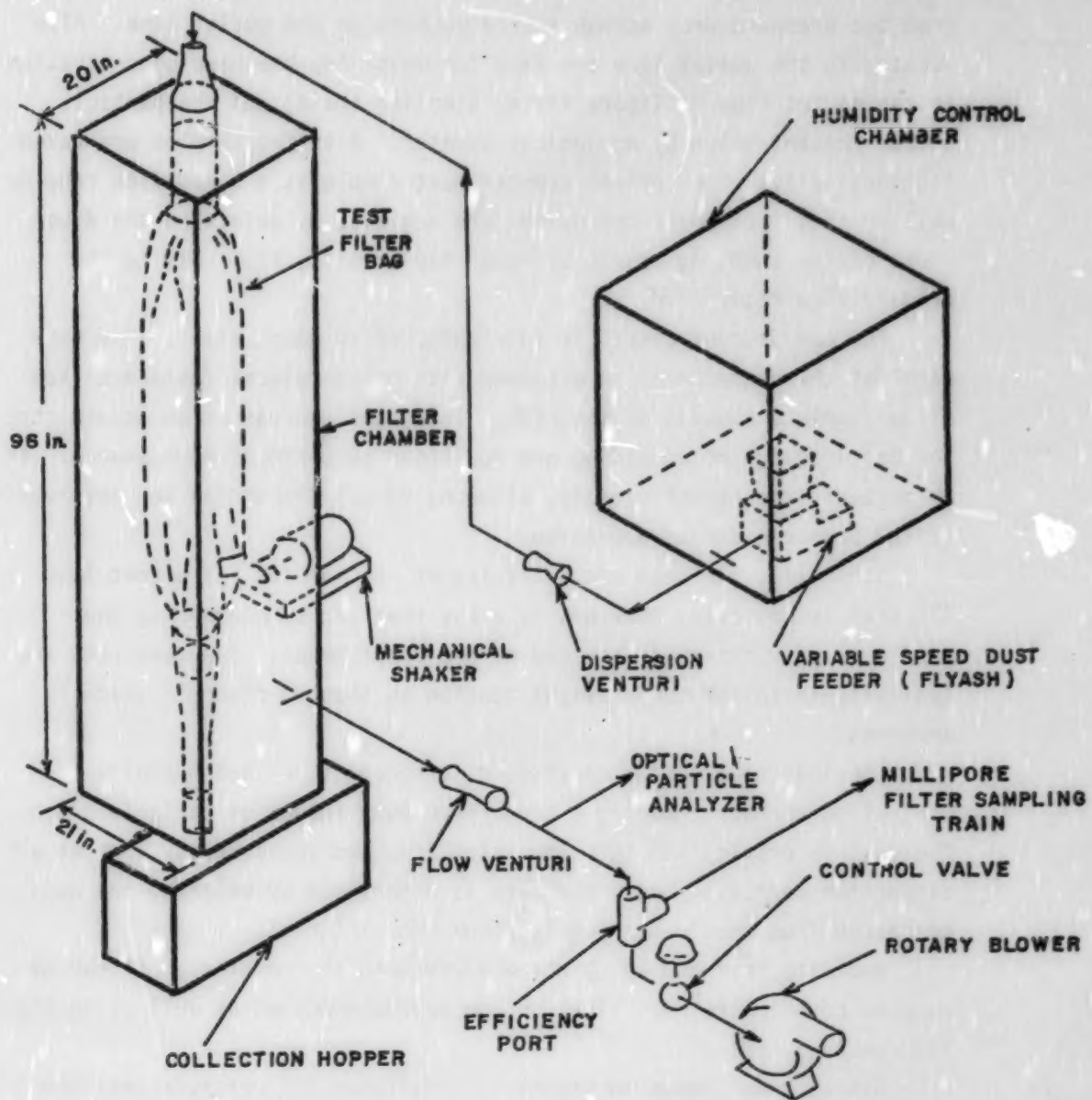


Figure 1. Test apparatus.

Air flow through the apparatus is by an induced draft, Roots type blower located in the outlet line. The primary air flow is determined from the pressure drop across a flow venturi in the outlet line. Also located in the outlet line are taps for measuring the mass concentration in the outlet (the Millipore filter sampling train) and the particle number concentration by an optical counter. Both the samples are taken isokinetically. The optical counter must sample at a fixed flow rate as well so that isokinetic conditions are achieved by selecting the dimensions of the sampling nozzle to match the sampling flow rate to the primary flow rate.

The compartment itself is fabricated of 10 gauge steel. One side panel of the compartment is attached with quick-release fasteners that allow complete removal of the side. This panel serves as an access port for bag loading and unloading and for inner compartment maintenance. It is made of transparent plastic, allowing visual inspection and observation of the baghouse during operation.

Nominally, the bags are 5-1/2 inches in diameter and 6 feet long. All that is required, however, is a bag that can be clamped to the nipple or an adapter at each end of the compartment. The test bags are typically installed under slight tension so that no droop or slack is apparent.

The induction system consists of a temperature- and humidity-controlled chamber, housing a screw-type dust feeder of variable pitch. The dust is gravity fed into the inlet line and subsequently through a dispersion venturi. Dust feed rate is determined by weighing the dust discharge from the feeder over a known time interval.

Humidity is measured by wet and dry bulb thermometers. It can be sampled both in the feed line and the baghouse outlet as well as in the room ambient air.

Although not shown in Figure 1, a differential pressure cell continually monitors the pressure drop across the test bag during the system operation. This pressure drop (plus that across the flow venturi), the system humidity and temperature, the dust feed rate, and the mass

and particle number analysis of the outlet constitute the primary measurements recorded during (or after) a run.

3.1.2 Experimental Programs (Shake-cleaned Baghouse)

One purpose of the in-house program is to identify and publicize fabrics that appear useful or advantageous in the control of fine particulates--especially for powerplant applications. Procedures and conclusions of this type of investigation are reported in Section 3.1.2.1.

Fundamental phenomena associated with fabric filtration have also been studied as part of the in-house research. An ambitious modeling of the fabric filtration process was concluded. New topics have been added and are reported in Section 3.1.2.2.

3.1.2.1 Fabric Filter Performance Evaluation -- A class of potentially useful filter fabrics evaluated by the EPA in-house facility is that called "spunbonded." These fabrics are non-woven fabrics deriving their strength and stability from bonds between touching fibers rather than a weave. These spunbonded joints are created by a heat treatment, by incorporating a lower melting copolyester, by physical softening and hardening using an appropriate solvent, or by some combination of these methods. Their chief virtue is low cost, since they are made by simply forming webs of continuous filaments and then bonding. Commercial spunbonded fabrics have been made from materials such as polyamides, polyesters, and olefins and marketed under various tradenames. This phase of the in-house research evaluated two representative fabrics: Cerex, a spunbonded nylon manufactured by Monsanto, and Reemay, a spunbonded polyester manufactured by DuPont.

Two categories of properties were used in the evaluations: performance and endurance. The performance parameters measured or calculated from the measured data were [Refs. 2,3]:

- 1) Collection Efficiency
- 2) Outlet Concentration
- 3) Effective and Terminal Drags
- 4) Specific Cake Resistance.

In general the preferred baghouse operation is one which maximizes parameter 1 and minimizes parameters 2 to 4. Parameters 3 and 4 measure the energy required to operate the baghouse. They are, respectively, the pressure drop across the bag per unit air flow through the bag and the rate of increase of this quantity. Hence they can be used to calculate the fan rating required for system operation and the frequency of bag cleaning.

Endurance was determined by counting the total number of shakes a bag could tolerate before showing irreversible degradation in performance. Typically endurance would be measured in an accelerated test cycle whereby the number of shake-clean oscillations per unit operating time was greatly increased over what it would be in an actual installation. Conversely the dust quantity passing through the bag would be less than realistic. Such departures from reality, however, made it possible to gather comparative bag life data in a practical calendar time period.

The results of the spunbonded tests have been published in References 2 and 3. When filtering redispersed flyash at room temperature, these tests show that the spunbonded fabrics display higher efficiencies and lower outlet concentrations than do woven fabrics of the same composition and weight. In addition the drags and specific cake resistances of the spunbonded fabrics are as low as or lower than those of the woven fabrics. Bag endurance appears to be not as great, however, for the spunbonded bags.

Based on these evaluations, spunbonded fabric filters warrant field testing. They cost less than woven fabrics and cost less to operate, but perform somewhat better--at least when filtering powerplant flyash at room temperature. Lower drags and specific cake resistances also mean that a bag does not have to be cleaned as often so even though the spunbonded bags do not tolerate as many total shakes as their woven counterparts, their superior flow interactions with flyash mean that they will not have to be shake-cleaned as often over a given period of operation. Just how these factors translate into bag life in an actual installation is not clear. Nor is it clear as to how to extrapolate the

endurance measurements made on this shake-cleaned test apparatus to the commonly used reverse-air or pulse-jet cleaned units. Relative fabric performance (collection efficiency, drags, etc.) would be expected to hold in these other installations but endurance could change significantly. The in-house EPA evaluation suggests that the spunbonded fabrics could provide an optimum cost-effective fabric for certain applications and further evaluation in field applications is warranted.

A third fabric evaluated in the shake-cleaned baghouse was an expanded polytetrafluorethylene (PTFE) laminate. The specific fabric tested consisted of a PTFE film supported on a woven Nomex scrim--the Gore Tex/Nomex fabric.

The test sequences were similar to those run on the spunbonded fabrics; both performance and endurance were measured. Reference 4 summarizes the results of this evaluation. Among the conclusions of the study was the hypothesis that the PTFE laminate fabric depends on sieving as the primary filtration mechanism when the dust is flyash (or any similarly sized dust, most likely).

This conclusion means that this dust/fabric interaction varies significantly from what is regarded as the "classical" particle capture mechanisms by fiber and fabric filters. These classical mechanisms are summarized in Figure 2.

- 1) Gravity -- Large particles ($>5 \mu\text{m}$ diameter) simply settle out of the gas stream. This action occurs independently of the fiber or fabric filter and depends upon gas stream velocity as well as particle mass.
- 2) Direct Interception -- The particle, in streamline flow, collides with the fiber.
- 3) Inertial Impaction -- The particle deviates from the gas streamlines because of inertial forces and strikes the fiber.
- 4) Diffusion -- The particle, being of the same magnitude in size as the molecules of the gas flow, moves in Brownian motion and has a finite probability of colliding with the fiber along its random path.

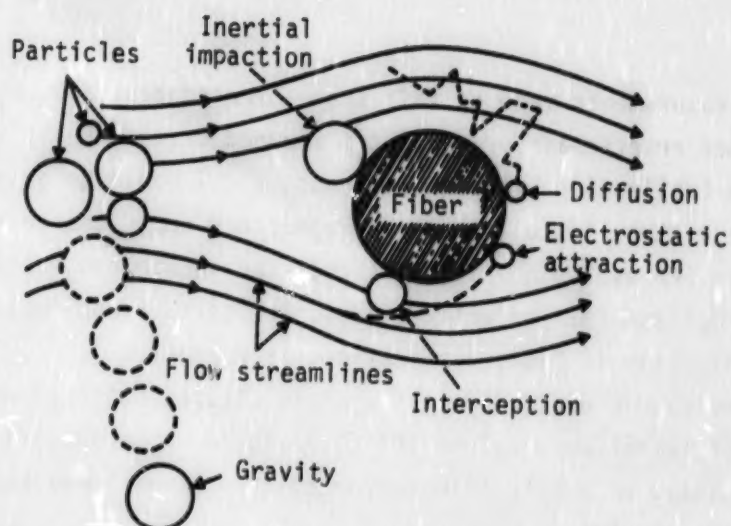


Figure 2. Mechanisms for particle removal by a filter [Ref. 5].

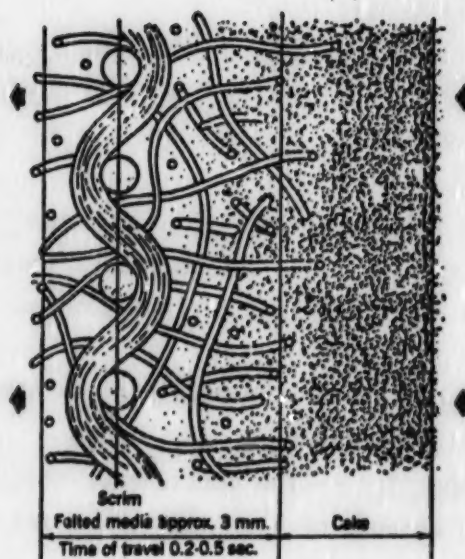


Figure 3. Section through felted filter media showing distribution of dust [Ref. 5].

- 5) Electrostatic Attraction -- Frictional charging of the fabric or particles creates electrostatic forces between the fiber and the particle which, depending on the species involved, can be the largest forces on the dust particle--at least in the vicinity of the fiber.

These mechanisms are generally accepted as describing the interaction between dust-laden air and a clean fabric filter. As the dust layer accumulates on the filter, however, the primary interaction then becomes one between the particles trapped in the dust cake and those in the gas stream (Figure 3). Only then does particle capture by sieving (particle capture because the openings in the fabric or dust cake are smaller than the dust particle) become an additional important capture mechanism.

For the PTFE laminate filtering flyash, sieving dominated from the beginning, making its behavior quite different from that usually observed.

Although the filtration efficiency of this fabric exceeded that of all others tested, flyash is probably not the optimum dust for evaluating Gore Tex/Nomex. The high fine-fiber content of this fabric suggests that it would be especially effective for filtering submicron dusts. This important property was not experimentally checked, however.

Other newly developed fabrics featuring special coatings, structure, or composition have also been briefly evaluated to determine baghouse potential. In general the most promising of these fabrics are those described in the published reports [Refs. 2,3,4]. The function of preliminary screening of new fabrics will continue as the search continues for better performing, less costly fabric filters.

Questions involving the suitability of fabric filtration for a specific application also have been addressed. For example, in response to a request from the USDA's Southern Regional Research Center, New Orleans, a brief evaluation of cotton dust filtering in the shake-cleaned baghouse was carried out. This investigation showed that the cotton dust/polyester fabric interaction allowed high efficiency filtration at relatively lower operating energy. The fabric released the dust easily during cleaning and gave no evidence of blinding. Testing was

far too brief to permit any conclusions regarding bag life and endurance but the application looks very attractive and could well lead to improved dust control at costs comparable to those for existing control methods. Assessing the suitability of specific dusts to control by fabric filtration will continue as part of the in-house program.

3.1.2.2 Phenomena Research -- Concurrent with or sandwiched between the fabric evaluation activities of the various shake-cleaned baghouses have been basic investigations of the dust/fabric interaction. A major activity of the in-house program was an attempt to model the performance of a filter fabric in terms of its structure. The significant, independent variables in the model included dust properties in addition to the various structural properties of the fabric. While the goal of establishing a quantitative, mathematical model was not achieved, the program did lead to important qualitative insights into the dust/fabric interaction [Ref. 6].

Highlights of this work included the experimental confirmation of the bridging phenomenon [Ref. 7], and of a critical pore size for bridging which is on the order of 10 times the mass mean particle diameter of the dust. The presence of fabric pores with dimensions exceeding this critical value leads to excessive dust seepage through the fabric. The concept of bridging arises from the commonly observed growth of particle chains as a result of particle capture by the fibers of the fabric filter [Ref. 7]. What this observation says is that, while the first particle deposited on a clean fiber may adhere at a random position on the fiber, the second, third and all subsequently deposited particles prefer to adhere to that previously deposited particle rather than to another site on the clean fiber. Consequently, the initial growth of dust cake is in the form of long, thin chains or filaments of deposited particles. These growths extend outward from the surface of the initial deposition site into the gas flow until the aerodynamic forces break them apart or until they reach some adjacent point of support, such as another fiber or another growing particle chain. Once a particle chain

establishes a stable anchor at its growing end, it has bridged a void and itself becomes a semi-permanent surface capable of particle capture in directions normal to its axis of growth. The critical pore size for bridging is about 10 particle diameters. When the average spacing between nearest neighbor fibers exceeds this distance, bridging becomes a low probability event and the filter continues to pass considerable dust along straight-through trajectories. If the average pore size is less than 10 particle diameters, significant bridging occurs and the filter rapidly blocks off most straight-through paths. The collection efficiency becomes very high. Unfortunately, the pressure drop across the filter also increases so that eventually some of the dust cake must be removed. The art of cleaning consists of removing enough of the dust to reduce the filter pressure drop, but not enough to eliminate all bridging particle chains. Generally a compromise can be easily established whereby both the pressure drops and the collection efficiencies cycle between acceptable limits.

The experimental program in support of this investigation examined over 100 fabrics of various sizes, construction, and composition using three different dust sources. Most data were collected using the shake-cleaned baghouses, but supplemental data were also gathered from measurements made with a small bench-scale filter system [Ref. 6]. This initial broad basic investigation has served as the foundation from which much later work has followed--in both the shake-cleaned baghouses and the pulse-jet baghouse to be discussed in Section 3.2.

One such investigation, carried out exclusively in the shake-cleaned baghouse, has been a study of bag aging effects. Performance parameters of woven polyester bags filtering flyash were measured over an extended period of time, simulating field use. An accelerated shake cycle was needed in order to complete a full life cycle in the laboratory test. A partial cycle was also carried out under operation more typical of field use. These data were used to identify and illustrate three stages of bag life: (1) break-in, (2) steady-state, and (3) wearout. Outlet concentration, for example, traces out the familiar bathtub curve with time; that is, it decreases initially during the break-in period, remains relatively constant during the steady-state, and rises rapidly

during wearout. The time dependence of collection efficiency and drag exhibits the inverse of the bathtub curve. Factors affecting the transitions from one portion of the curve to the next include both the dust loading and the cleaning parameters--the more dust remaining on or in the fabric, the higher its collection efficiency but also its drag. The details of where the dust resides in the fabric and how it "works" its way through are less well understood than the straight-through/single-capture models (Figure 2) applicable to single fibers [Ref. 8]. Reference 9 summarizes the initial experimental work and conclusions on this broad subject.

3.2 PULSE-JET BAGHOUSE

The pulse-jet baghouse used in the EPA in-house work is a commercially available Mikro-Pulsaire Dust Collector purchased from the Mikro-Pul Division of the United States Fiber Corporation. It has been used on several studies and evaluations and is continually being modified and improved. Plans for its use are growing.

The organization of this section is as before, the equipment being described first (3.2.1), followed by a brief review of the experimental highlights to date (3.2.2).

3.2.1 Description of the Pulse-jet Baghouse

The pulse-jet apparatus used for all EPA in-house work is a commercially available, nine-bag Mikro-Pul baghouse (Figure 4), consisting of three rows of three bags each. The cross section of the housing is square (34 inches on a side); it is 103 inches long. The dust-laden air enters at the bottom of the compartment and is drawn through the bags, into the clean air plenum, and out to the analytic line. Bag cleaning is by directing a short (~ 0.1 sec) pulse of high pressure air through the venturi nozzle located in the top, open end of each bag. The venturi shapes the air pulse and aspirates additional air flow from the plenum to create a shock wave that travels the length of bag and back. This action snap-cleans the bag by dislodging the accumulated dust cake from its outside surface. The agglomerated dust cake drops into the collection bin below.

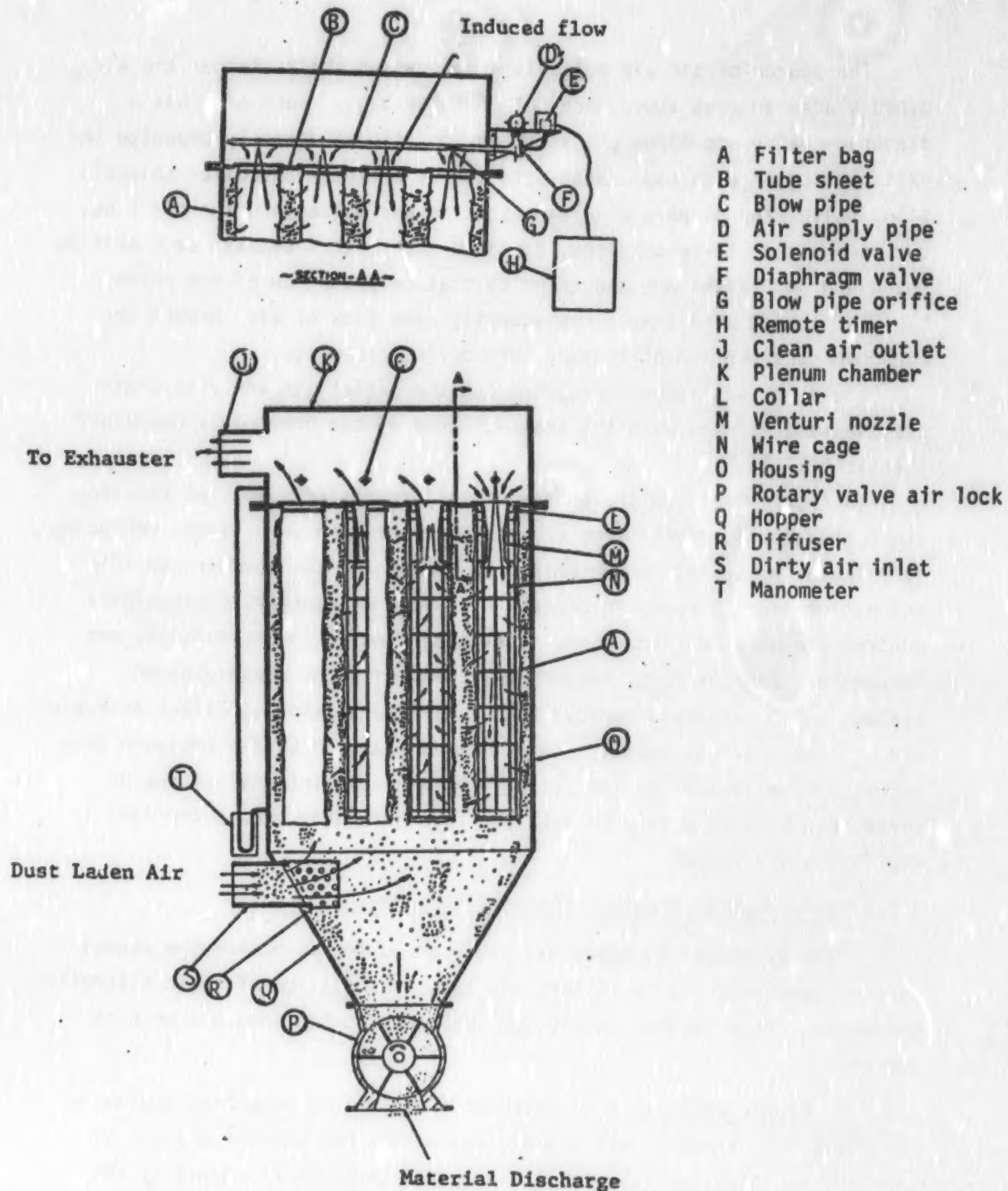


Figure 4. Schematic of Mikro-Pulsaire collector.
(reproduced with permission of the Mikro-Pul Corporation, Summit, N. J.)

The source of the air pulse is a compressor which charges the air pipes placed in rows above each set of three bags. Each pipe has a diaphragm valve and three orifices, one positioned directly opposite the exit opening of each bag. When actuated by a timer-controlled solenoid pilot valve, the diaphragm valve passes an air pulse into the air pipe, out each of the three orifices, and into the venturi beneath each orifice. The diaphragm valves are sequenced so that only one row of the three bags is cleaned at a time. Consequently, the flow of air through the baghouse continues uninterrupted even during cleaning.

The dirty-gas induction system and the outlet gas analytic chain are the same as used with the shake-cleaned system previously described (Section 3.1.1).

In fact installing the pulse-jet unit consisted simply of removing the baghouse compartment from one of the shake-cleaned systems, replacing it with the pulse-jet compartment, and hooking up the appropriate inlet and outlet lines already in place. Dust feed and temperature-humidity control are by an Acrison screw type feeder and an Inreco Humidity and Temperature Control Unit, respectively. As with the shake-cleaned system, outlet analysis employs both a Millipore sampling filter assembly and a Climet optical counter. Air flow is measured by the pressure drop across a flow venturi in the outlet line and is maintained at the desired flow rate by a flow controller. Pressure drop across the bags is continuously recorded.

3.2.2 Experimental Programs (Pulse-jet Baghouse)

The pulse-jet baghouse has also served two purposes--the evaluation of candidate fabric filters and the investigation of basic filtration phenomena. This section is divided into two subsections, one on each aspect.

3.2.2.1 Fabric Evaluation -- Although various bags have been tested in the pulse-jet baghouse, the primary evaluation has been of a class of needled, uncalendared felt fabrics prepared under an EPA grant by the Schools of Engineering and Textiles at North Carolina State University (NCSU) [Ref. '10]. These felts were evaluated in support of a study of the relationship between fabric structures and filtration performance.

Variations in needling technique (depth and spacing, dimensions), fabric structure, weight, and density were correlated with filtration performance both in the EPA pulse-jet baghouse as well as in a filtration apparatus at NCSU. From the comparative measurements of the NCSU-prepared felts with those already commercially available, it could be seen that under most normal operating conditions the NCSU fabrics were superior [Ref. 10]. At high dust loading and at high air-to-cloth ratios, however, cleaning difficulties were severer with the NCSU fabrics than with the commercial fabrics [Ref. 10].

Other fabrics have also been evaluated in the EPA pulse-jet unit. These evaluations have been brief and were generally terminated early because of obvious fabric deficiencies. Among these brief evaluations was a high pile fabric which showed promise because of its low pressure drops. Unfortunately this fabric proved to have poor collection efficiency from the beginning. With service, the efficiency degraded further as though the fabric pores were stretching to pass large quantities of dust.

3.2.2.2 Specific Research -- The key experiment performed in the pulse-jet baghouse was a comparison of the penetration of two types of test dusts--rock dust and Detroit Edison flyash--through two types of felt bags, Dacron and Nomex. This research actually responded to requests for information and assistance from members of the asphalt industry as well as from non-R&D segments of EPA, but provided valuable, supplementing information on the effect of changing dusts. The rock dust used for experimentation was finer than the flyash; its mass median diameter (D_{50}) was on the order of $2.5 \mu\text{m}$ as compared with a D_{50} for flyash of $4.0 \mu\text{m}$ or greater. Both types of fabric filter bags showed consistently higher pressure drops, higher values of specific cake resistance, and more dust penetration when filtering the rock dust than when filtering the flyash. For both fabrics, the collection efficiency increased with increasing inlet loading more significantly for rock dust than for

flyash. The type of dust is clearly of first order importance in determining filtration behavior. While both fabrics could efficiently remove rock dust from the air flow, it was more costly and more difficult to remove than flyash.

This investigation also looked for fabric blinding or the suggestion of blinding when filtering these dusts. No concrete evidence of blinding was observed using either fabric with either dust. The maximum dust loading employed, however, was on the order of 12-13 grains/ft³ so that the occurrence of blinding in a field installation (operating at, say, 100 grains/ft³ of inlet dust) could not be ruled out.

An interesting sidelight of this work came about by continuously recording the output of the optical detector. The trace reveals pulses of penetrating particles corresponding to the time periods of the bag cleaning pulse, confirming the results of other investigations that the bulk of the particles that penetrate the fabrics do so during or immediately after the cleaning pulse. This conclusion is particularly striking for the flyash particles larger than 1 μ m. At 0.3 and 0.5 μ m the penetration of flyash is more uniform. Rock dust, on the other hand, shows strong pulse-related penetration over all size ranges, although the peaks become broad for the submicron dust populations. Recovery of high efficiency of filtration following a cleaning pulse takes a significant fraction of the filtration period when filtering submicron rock dust.

While both the Dacron and Nomex fabric filters displayed high collection efficiencies (99+%) under all test conditions, both bags filtered the flyash more efficiently than the rock dust (99.9% for flyash vs. 99.9% for the rock dust). The major differences were in the much higher pressure drops (5-7 in. H₂O for rock dust vs. 1-3 in. H₂O for flyash) and specific cake resistances (>20 in. H₂O/fpm/lb/ft² for rock dust vs. 2 to 5 in. H₂O/fpm/lb/ft² for flyash) characteristic of rock dust filtration. Type-of-fabric differences were smaller than the type-of-dust differences. The experimental results served to emphasize once again the importance of the dust itself in selecting optimum operating conditions. One cannot blithely assume that what works well for one dust

will work equally well for another. In the absence of adequate understanding, as is true for the present state-of-the-art, some experimental trial and error seems necessary before making major commitments to any particular mode or range of operation.

This uncertainty that characterizes fabric filtration restricts the rate at which the method will be accepted. An urgent goal of the EPA in-house program in fabric filtration (and the outside contractor/grantee program as well) continues to be better understanding of the process whereby field results can be better predicted and designed for, reducing costly full scale corrections and surprises and the preliminary trial and error procedures now needed to avoid them.

3.3 HIGH TEMPERATURE BAGHOUSE

The high temperature baghouse was built in order to investigate fabric endurance at high temperature. At the time of its construction few, if any, experimental baghouses had a high temperature capability. The role of this apparatus, now dismantled, was to evaluate fabric endurance at the high temperatures more closely corresponding to field conditions. The hope was that this apparatus, because it allowed more realistic testing than could be found with standard fabric tests, would provide a better measure of fabric life in the field. The results, when compared with field tests, were anomalous and the decision was made to design a more versatile unit before doing further testing of high temperature fabrics.

The unit had a four-bag capacity and operated on a dust batch basis (Figure 5). A given quantity of dust in a heated air flow would be filtered by the fabric. The filtration period was 75 secs after which the fabric was shake-cleaned for 35 secs. During cleaning, the dust dropped to the bottom of the bag into the dust pot. The dust pot contained a blow pipe system through which the hot air of the next filtration cycle entered and redispersed the dust. The dust became reentrained and recaptured by the fabric filter. Except for pressure drops across the bag, no measurements of filtration efficiency or other filter performance parameters were made. The evaluation was of endurance only so the apparatus simply cycled the dust on and off the fabric in a high temperature gas flow. Coulter counter analysis of the dust did show

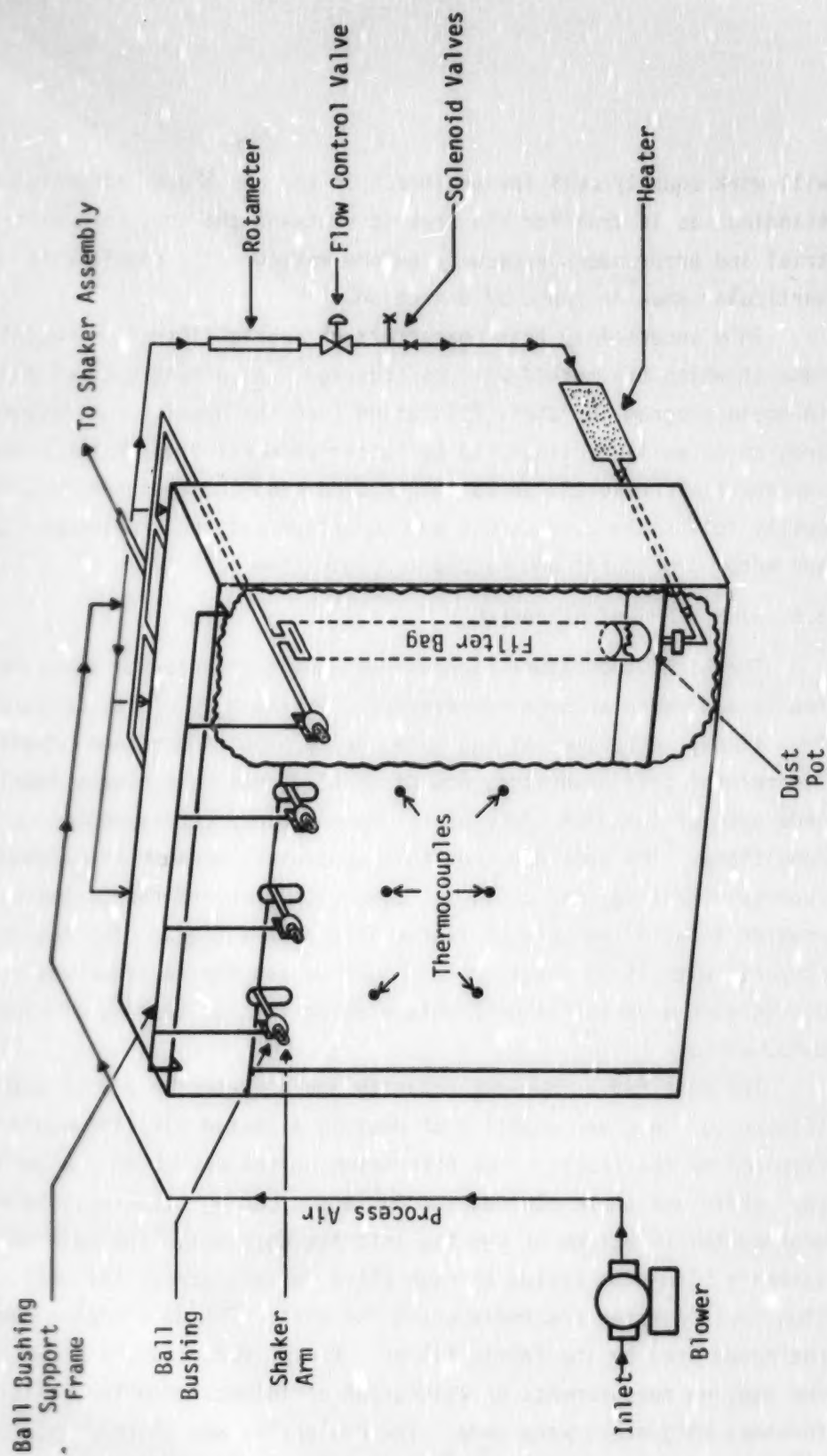


Figure 5. Laboratory baghouse for high temperature tests.

that the mass median diameter increased slightly with time of operation, presumably because more of the finer particles penetrated the fabric and were lost from the recycled dust supply.

The fabrics evaluated were made mostly of fibrous glass coated with one type of surface finish or another in an effort to improve bag life. One series of tests was run, however, to test the cleaning recommendations generated from contract work done by GCA Corporation [Ref. 11]. The recommendations were for higher cleaning frequency and generally greater amplitude than normally used. The purpose of the high temperature baghouse testing was to ensure that commercial fabrics could be cleaned at the recommended conditions and at their maximum recommended service temperature without severe degradation of the fabric.

Among the fabrics tested were woven cotton (operated at 180°F) and woven polyester (operated at 275°F). These woven fabrics withstood over 2 million shakes at high temperature without failure. The tests showed that high temperature operation did not alter the cleaning recommendations in any major way [Ref. 12].

The one felted wool fabric tested (also at 180°F) failed when subjected to a period of shake-testing but a relatively early failure was expected. Felts are not ordinarily used in shake-cleaned units and cannot withstand the stresses imparted by shaker mechanisms.

3.4 THE VERSATILE FABRIC FILTER TEST UNIT

New apparatus is now being built for continuing the high temperature testing. This equipment will also be capable of simulating operation in acidic environments and at various dust loadings and humidities, opening up new areas of research (such as reagent injection filtration, whereby selected gases are removed by the filter after being adsorbed by an appropriate injected sorbent reagent). Bag cleaning will be by any of the three common methods: mechanical-shake, reverse-air, or pulse-jet. With the completion of this facility in 1977, the in-house test program will for the first time have a reverse-air cleaning capability. Table 1 summarizes the range of operating variables being built into this equipment. Each of the four bags is mounted in a separate

TABLE 1. OPERATING RANGE OF THE VERSATILE FABRIC FILTER TEST UNIT

Variable	Range
Temperature	70°F to 1500°F
Bag face velocity	1 to 12 ft/min
Humidity	Dew point of 32°F to saturation. Above 212°F, up to 20 percent by volume.
Number of bags	4
Bag size	35.5" overall length; 2.5" cuffs; 5" inside diameter; variable L/D
Cleaning methods	Mechanical shake Frequency: 0 to 20 cps Duration: 0 to 60 min Amplitude: 0 to 1 in Reverse flow Duration: 0 to 15 min Repetition rate: variable Reverse pulse Repetition rate: variable
Reactive fluids	SO ₂ : 100 ppm to 10 percent SO ₃ : 5 to 500 ppm Cl ₂ or HCl: 100 to 1000 ppm HF: 5 to 100 ppm
Grain loading	0.05 to 15 grains/ft ³

isolated compartment that is fitted with a changeable lid corresponding to the chosen cleaning technique. While each compartment is fed from a common input gas line, it will be possible to simultaneously test different fabrics and to shut off one or more compartments off while continuing to run on the others.

The instrumentation built into the bag housing includes the measurement of the mechanical tension under which the bag is mounted. Tension can be adjusted at operating temperature to eliminate uncontrolled changes because of differing thermal coefficients of expansion between any given bag and the housing. In addition to the standard monitors for temperature, pressure, and humidity, a provision for measuring electrostatic charge on the bag surface is also included. This measurement is by an electrostatic probe on which the electrostatic charge induces a voltage. A 30-channel data logger keeps a running record of the many dependent and independent variables.

The availability of this test equipment will open up new horizons for the in-house program. Research previously beyond the scope of the in-house facility will become possible.

SECTION 4

FUTURE WORK

Over the near term the in-house program will continue evaluations of specific fabrics and investigations of the basic mechanisms of fabric filtration. A highlight of the coming year is the acquisition of a versatile, high temperature test facility (Section 3.4). This new equipment will not only replace an older unit used for high temperature tests, but will also add new test capability such as reverse-air cleaning, electrostatic charge measurements (by an induced voltage), and measurement of bag tension. Thus the in-house program, while pursuing the same dual goals as in the past, will have greatly enhanced capability for both evaluation and investigation. This section discusses several tasks of the immediate future.

4.1 EVALUATION OF HIGH TEMPERATURE FABRICS

One limitation to fabric filter applications and/or techniques is that imposed by the temperature stability of the fabrics. Present commercial fabrics--at least those in widespread use--cannot operate continuously at a temperature in excess of 500-550°F, and only the most temperature-tolerant of the commercially available fabrics (fibrous glass) can operate at this temperature. Most fabrics have far lower temperature limitations.

A potentially significant payoff awaits the developer of a fabric capable of operating at much higher temperatures. For example, particulate removal from the fuel gas used to fire a COGAS* turbine must be

*COGAS, COmbined GAs and Steam power system.

very efficient--much better than is required for ambient air standards. Failure to meet this requirement would jeopardize the proposed scheme of coal gasification/power generation. Fabric filtration can meet the particulate removal requirements, but present fabrics introduce the need for a fuel gas cooling step between the gasifier and the COGAS power system, severely penalizing the overall efficiency of the coal-to-power conversion. Having a high temperature fabric that could eliminate the need for fuel gas cooling would be highly desirable, perhaps necessary.

The availability of high temperature fabrics in general enhances the range of interactions and reactions that can be carried out--high temperature fabrics imply more process versatility. For example, the adsorption of SO_2 by a nahcolite-seeded gas is more efficient at high temperature. Removal of SO_2 in a dry scrubbing process such as nahcolite adsorption would, of course, greatly enhance the value of fabric filtration to operators of coal-fired boilers.

Because of their value, then, high temperature fabrics are continually being developed. A key part of the near-term fabric evaluation at EPA will be performance measurements on candidate high temperature fabrics such as woven stainless steel, glass-asbestos, and those woven from alumina-boria-silica fibers. The initial tests will be at room temperature and, with the availability of the versatile fabric filter test unit, high temperature testing is also planned.

Other fabrics will continue to be tested with appropriate dusts as the need for evaluation arises. New fabrics developed to possess superior properties of some sort--acid resistance, abrasion resistance, etc.--or lower costs are expected to remain part of the fabric evaluation program throughout the foreseeable future. All the existing experimental baghouses will participate in this function from time to time as will the new versatile baghouse.

4.2 FABRIC FILTRATION RESEARCH

The fabric filtration industry operates largely in the empirical mode. New installations are designed on what has worked in similar, previous installations. A new dust to filter typically means small

scale testing to confirm a workable set of operating parameters on which to base a full scale design. This empirical procedure is required because not enough of the significant parameters of the dust/fabric capture and release processes are understood. The EPA in-house program continually undertakes research that will lead to a better understanding of the science underlying fabric filtration. This section lists three experiments now either underway or in the formative stages. These three and others will be part of the in-house basic research work for the coming year.

4.2.1 Dust Penetration Studies

All the mechanisms of dust penetration through a fabric filter are not yet understood. The delayed component of dust penetration--that which does not pass straight through without collision or temporary capture--makes up a complex sequence of interactions which depend on many variables, many of which have not yet been identified. The ongoing in-house work is investigating the properties of the delayed component of dust penetration for various dust/fabric systems. This work will continue with the goal of developing models by which the magnitude and behavior of this component can be predicted.

4.2.2 Cleaning Characteristics of Jet Pulses

The cleaning efficiency of a jet pulse used in a pulse-jet baghouse depends on the properties of the jet pulse in addition to the bag properties and the dust/fabric interactions. Among the major independent variables of any specific pulse jet are the pressure and duration of the initiating air. If the shaping venturi and the plenum are assumed fixed, as well as the orifice dimensions and position of the blow pipe, then pulsing pressure, duration, and frequency are the primary controls over the pulse-jet cleaning. Work is now underway to correlate these independent variables with bag cleaning efficiency and also dust penetration. Triggering circuits, now incorporated into the pulse-jet baghouse, allow correlation between bursts of penetrating particles (detected optically in the outlet) and the independent variables used to form the cleaning pulse. Improved understanding could lead to more efficient cleaning at lower costs in energy, making a more desirable baghouse operation.

4.2.3 Electrostatic Interactions

Electrostatic interactions can dominate the dust/fabric interaction under certain conditions, as has been dramatically demonstrated on numerous occasions. Unfortunately such demonstrations have not yet led to adequate understanding of the role of electrostatic forces in fabric filtration or to useable models for predicting the magnitude or importance of electrostatic forces in a given dust/fabric system. Now being developed at the in-house facility is a technique for measuring electrostatic charge buildup on a bag during pulse-jet operation. The technique consists of measuring the voltage on the electrically isolated cage during operation and requires only the addition of a wire lead to the cage on which to measure the voltage (or alternatively the charge). The wire cage, being in intimate contact with the bag at many discrete points, is assumed to acquire charge from the fabric. This charge corresponds to an average electrostatic charge buildup on the fabric. The method does not depend totally on induced voltage; it allows actual charge transfer between the fabric and the wire cage. It has the merits of being simple to implement and of introducing only minimal disturbances into the standard equipment found in the field. This latter feature promises observations in the laboratory that correspond closely to what is observed in actual installations.

SECTION 5

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APPENDIX CONVERSION FACTORS

<u>To Convert from:</u>	<u>To</u>	<u>Multiply by:</u>
grains/foot ³	kg/m ³	2.29×10^{-3}
foot	meter	3.05×10^{-1}
inch	meter	2.54×10^{-2}
grain	kilogram	6.48×10^{-5}
inch of water (60°F)	newton/meter ²	$2.49 \times 10^{+2}$
foot/min (fpm)	meter/sec	5.08×10^{-3}
$\frac{\text{in. H}_2\text{O/fpm}}{\text{lb(m)}/\text{ft}^2}$	$\frac{\text{newton-sec}}{\text{meter-kg}}$	10^4
°F	°K	$^{\circ}\text{K} = \frac{5}{9} (^{\circ}\text{F} + 459.67)$